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From BIM (Building Information Modelling) to BEM (Building Energy Modelling): a collaborative approach

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Abstract

The use of simulation to predict building energy performance has been shown to have significant benefits in terms of reducing energy consumption and greenhouse gas emissions. However, in terms of implementation, the process can be disjointed and messy, with a lack of integration between architects and engineers. For the process of creating a building energy simulation to be more efficient, a seamless transition from an architectural design to an energy model is required. This paper highlights some of the practical issues manifest in the process of data exchange for energy analysis. It presents a proposed workflow for the exchange of data between architectural professionals and mechanical engineers for the purposes of building energy simulation. The workflow is based upon the information delivery manuals (IDMs) from buildingSMART using non-proprietary industry foundation class (IFC) format, in order to ensure its wide scale adoptability. Construction material parameters are integrated within the architectural building information model (BIM) allowing for improved transparency between the disciplines in both directions. This methodology also enables an iterative design process, reducing the amount of modelling work required by the engineer and allowing for better informed design decision-making by the architect. This offers the potential to reduce costs, and avoid unnecessary delays and miscommunications.

Keywords

information, modelling), bem, (building, energy, bim, modelling):, collaborative, approach

Disciplines

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FROM BIM (BUILDING INFORMATION MODELLING) TO BEM (BUILDING ENERGY MODELLING): A COLLABORATIVE APPROACH

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ABSTRACT

The use of simulation to predict building energy performance has been shown to have significant benefits in terms of reducing energy consumption and greenhouse gas emissions. However, in terms of implementation, the process can be disjointed and messy, with a lack of integration between architects and engineers. For the process of creating a building energy simulation to be more efficient, a seamless transition from an architectural design to an energy model is required. This paper highlights some of the practical issues manifest in the process of data exchange for energy analysis. It presents a proposed workflow for the exchange of data between architectural professionals and mechanical engineers for the purposes of building energy simulation. The workflow is based upon the information delivery manuals (IDMs) from buildingSMART using non-proprietary industry foundation class (IFC) format, in order to ensure its wide scale adoptability. Construction material parameters are integrated within the architectural building information model (BIM) allowing for improved transparency between the disciplines in both directions. This methodology also enables an iterative design process, reducing the amount of modelling work required by the engineer and allowing for better informed design decision-making by the architect. This offers the potential to reduce costs, and avoid unnecessary delays and miscommunications.

1.0 INTRODUCTION

Energy simulation tools are now commonly used within the building design process. They allow designers to predict the energy required to provide internal environmental comfort, whilst delivering a desired level of energy efficiency. Construction professionals are increasingly being required to use building energy simulation to meet performance based regulation, such as the National House Energy Rating Scheme (NatHERS) in Australia (Department of the Environment and Energy, 2016).

In the move towards more sustainable buildings, it is necessary for construction professionals to work more closely in a multi-disciplinary team (Robichaud and Anantatmula, 2011), with a common goal of reducing both the energy and environmental footprints of new buildings. The International Energy Agency (IEA) has identified an integrated design process (IDP), delivered through a multi-disciplinary design team, as a '*prerequisite for successfully achieving sustainable buildings*' (Lohnert, Dalkowski and Sutter, 2003, p. 2). Within the construction industry, however, the required level of multi-disciplinary collaboration in building design is not commonplace.

Conventional methods used within the design process have been changing, from 2D Computer Aided Design (CAD) to Building Information Modelling (BIM). BIM has previously been defined as '*a set of interacting processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle*' (Succar, 2009). The use of BIM is reported to offer many benefits including: improved accuracy, time savings, cost reduction, quality improvements, more rigorous design and analysis processes, coordination improvement, and the ability to predict environmental and lifecycle performance (Azhar, 2011; Bryde, Broquetas and Volm, 2013).

It has been suggested that the use of energy simulation during the early building design stages can better inform design decision making (Bleil De Souza, 2013; Cemesova, Hopfe and McLeod, 2015). However, multiple barriers exist which can prevent this from happening. Firstly, developers are often reluctant to employ comprehensive teams of professionals from the early stages of a project (Robichaud and Anantatmula, 2011). Therefore, in many cases, teams are lacking an engineer at this stage and it is either necessary for an architect to undertake (sometimes crude) energy modelling themselves, or simply to design based on their prior experience. Secondly, interoperability between BIM and energy simulation tools is currently problematic (Cemesova, Hopfe and McLeod, 2015), typically resulting in architects communicating the design of a building in one model and an energy consultant reproducing that design within a Building Energy Model (BEM) (Bazjanac, 2008; Marsh, 2015; Negendahl, 2015). Thirdly, it has been suggested that a fundamental difference in paradigms exists between engineers on the one hand and designers on the other (Bleil De Souza, 2012). It is therefore important for both disciplines to develop an understanding of the needs of the other at both a high level and a detailed level.

This paper has been developed as a result of interdisciplinary research work being undertaken in the Steel Research Hub[1]. Within this research program, an archetype mid-rise residential building has been designed on a notional site in Sydney. The building is seven storeys above ground level with a single basement car park level. The building contains 60 apartments of varying size from 1 to 3 bedrooms. The building has been designed to be typical of the mid-rise residential sector, and has been modelled using Autodesk Revit. Within this research, the predicted energy consumption of this building is of interest. The process of translating models between BIM and BEM has been undertaken using current best practice procedures, including following the Information Delivery Manual (IDM) originally developed for buildingSMART (See and Welle, 2009). Despite the use of best practice techniques and procedures, the process of transferring the building geometry between BIM and BEM has proven to be problematic.

This paper presents a methodology for collaborative multi-disciplinary working to enable a smooth and iterative, integrated design and energy modelling process and to help overcome some of the barriers to the successful use of BEM in the early design stages. The paper also discusses some of the issues encountered when employing an interdisciplinary approach and ways in which these issues might be overcome.

2.0 DATA EXCHANGE FOR ENERGY ANALYSIS

[1] ARC Research Hub for Australian Steel Manufacturing

2.1 Information required for energy analysis

An engineer has certain requirements for the information they receive within a conceptual design model. To support energy analysis using building thermal modelling, their requirements for geometry and metadata are:

- Building geometry including the layout, configuration of spaces, and building orientation;
- Building construction including the thermal properties of all construction elements including walls, floors, roofs/ceilings, windows, doors, and shading devices;
- Building usage including functional use.
- Geographic location of building site.

Methods to check for this content are often not digtially based, and manual checking is necessary. For automated computer analysis of digital models to occur, there need to be specific definitions of model content. A framework for this was developed by buildingSMART International.

2.2 Information Delivery Manuals

The role of the international organisation, buildingSMART, is to implement digital interoperability into the global construction industry. Over the past 20 years, buildingSMART has developed processes and documents that now form part of ISO Standards. In the area of structured data exchanges, it has created Information Delivery Manuals (IDMs) to guide the process of data exchange. The IDM for BIM Based Energy Analysis (See and Welle, 2009) provides a systematic and comprehensive methodology for an architectural concept design model to be used in model-based energy analysis. It contains a process map of the required workflow between architects and engineers to achieve the overall goal of a project. The IDM defines: the purpose of the digital exchange, who authors and receives it, the project phase of the exchange, as well as the geometric objects and their metadata. The iterative process of information exchange that is required among the stakeholders is defined. These exchanges include those between the design team, building owner and consulting staff, over every step of the design process, from conceptual design to final detailed design. This detailed approach creates the potential for the use of automated model checking to ensure all the required information is present (an example from Solibri Model Checker (SMC) is shown in Figure 1). SMC facilitates the checking of a BIM against selected parametrically defined rules, such as space requirements, shape overlaps, or naming conventions (Eastman *et al.*, 2009) to name a few. The IDM also removes the need for detailed data exchanges to be defined on a project-by-project basis, providing an open, non-proprietary, software agnostic process. The IDM has the potential to be used by project managers, software developers and model authors to deliver interoperability to industry practice.

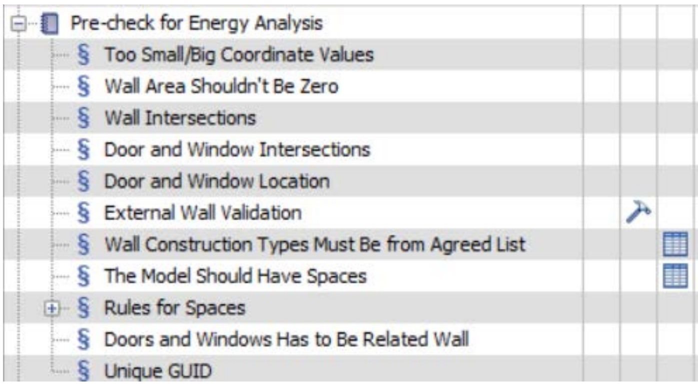


Figure 1: An example of automated model checking rulesets from Solibri Model Checker

2.2 Issues of interoperability

However, practical issues can arise from collaborative interdisciplinary work. The current study has highlighted that the seamless use of a model developed by architects, and subsequently used by thermal engineers is not a trivial exercise. Often, models developed by an architect are not readily usable if exported to suitable building thermal modelling software such as DesignBuilder. The major issues encountered are geometric flaws and data degradation in the transfer process (Porwal and Hewage, 2013). The geometric flaws are found to be of major consequence for engineers.

In terms of data degradation, previous research has determined that it is typically necessary to process model geometry in the export from BIM for the purposes of energy simulation (Cemesova, Hopfe and McLeod, 2015). Negendahl (Negendahl, 2015) identifies the need for architects to provide '*BPS [building performance simulation] friendly geometry*' through the use of automated or semi-automated algorithms. In the case of PassivBIM, a tool for first extracting geometric data from an industry foundation class (IFC) file and then combining this with data from the PassivHaus Planning Package (PHPP) energy simulation tool, it was found to be necessary to pre and post-process various geometries. This tool now enables the rapid design optimisation of buildings with the aim of achieving the Passivhaus standard. In the buildingSMART IDM (See and Welle, 2009) it is postulated that in time, building simulation software developers will accommodate similar necessary pre and post-processing within their import functions to better support the necessary interoperability.

There is also a need for checking of model geometry for continuity of building surfaces to precisely define enclosed spaces. The IDM does not adequately address these geometric requirements.

Within this research, computer-assisted geometric model checking was used to investigate clashes and gaps of building surfaces. Prior to exporting model geometry for energy analysis to .gbxml format, Revit provides an analysis to allow gaps to be identified (see Figures 2 and 3). Model checking using Solibri Model Checker also provides an automated process for identifying geometric issues (Figure 4).

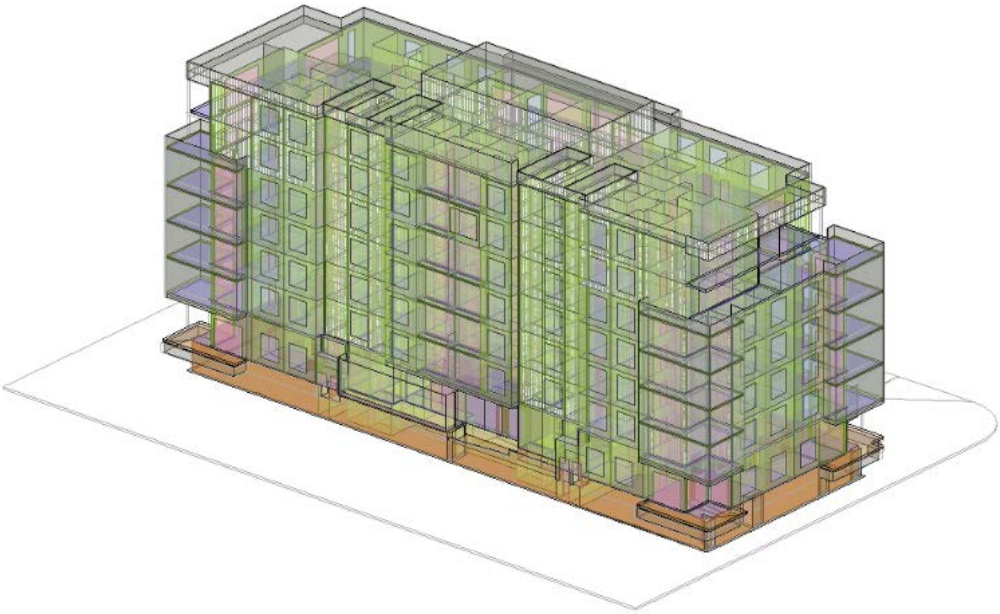


Figure 2: 3D Model

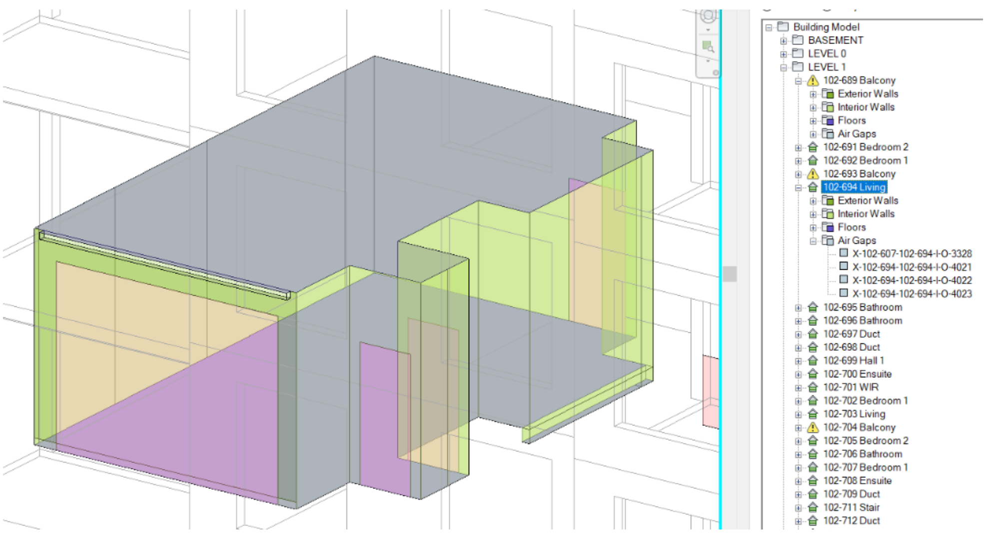


Figure 3: *.gbxml file of room with air gaps identified

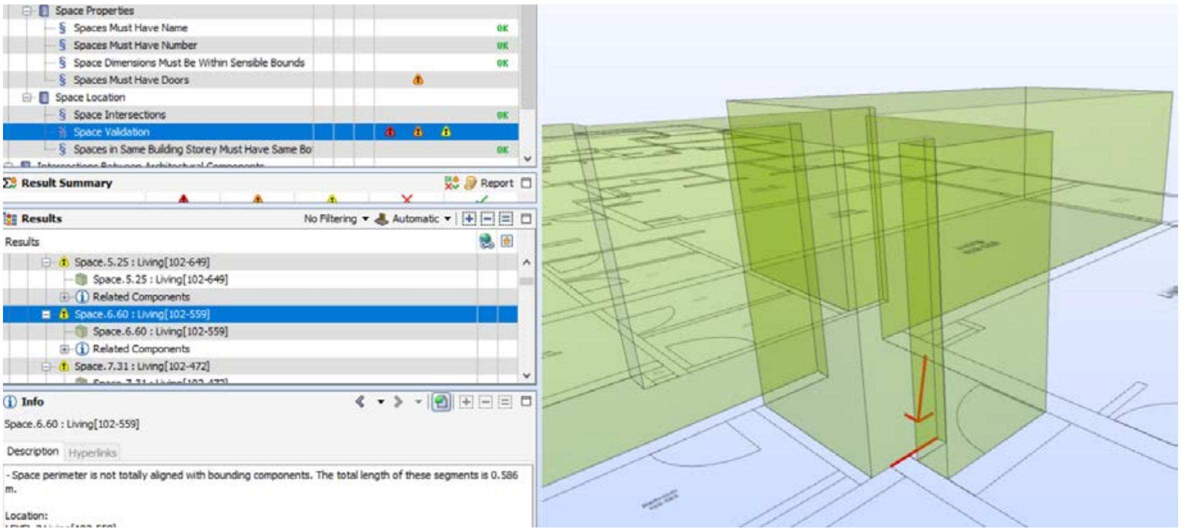


Figure 4: Room boundary errors identified in Solibri Model Checker

2.3 A proposed workflow

It is proposed here, that to make a BIM developed by architects capable of being used seamlessly by engineers, collaboration across the disciplines must start at a much earlier stage, even before any model is built (Lohnert, Dalkowski and Sutter, 2003). The aim is not to increase the burden on the architect. On the contrary, the aim is to open up the possibility of BEM more seamlessly informing the design process for the attainment of sustainability goals. This workflow provides a more specific and detailed focus on the integrated BIM and BEM processes than the higher level IEA IDP. For complex buildings, engineers must test a conceptual model, developed by architects, for inaccuracies at an early stage. If any flaw is detected, it must be rectified before one can move to the next stage. In the next stage, partitions can be added to the building and tested for errors. Further details can be added when the model with enclosed spaces is fully functional. Figure 5 summarises the conceptual workflow. Step 1 is a critical process to ensure that a model developed in BIM works in thermal modelling software. Steps 2 to N are as required within a particular project and an optimum number should be determined to improve efficiency and reduce the number of iterations, reducing the cost. Over time, with experience, the number of iterations is expected to decrease.

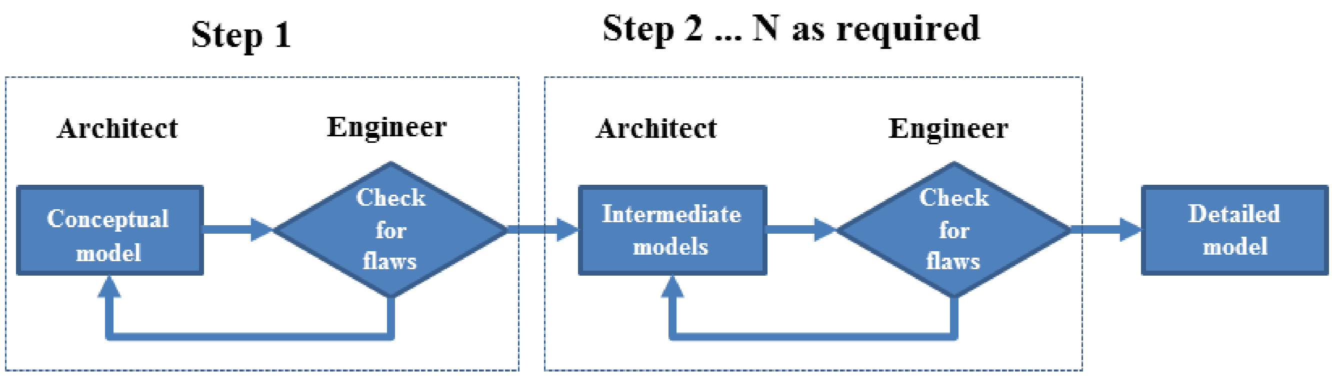
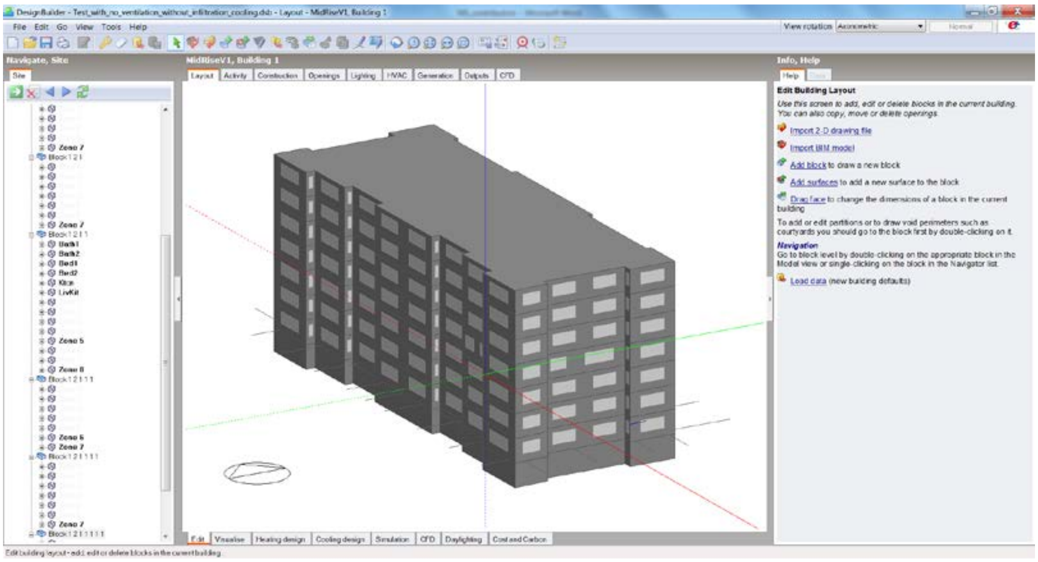


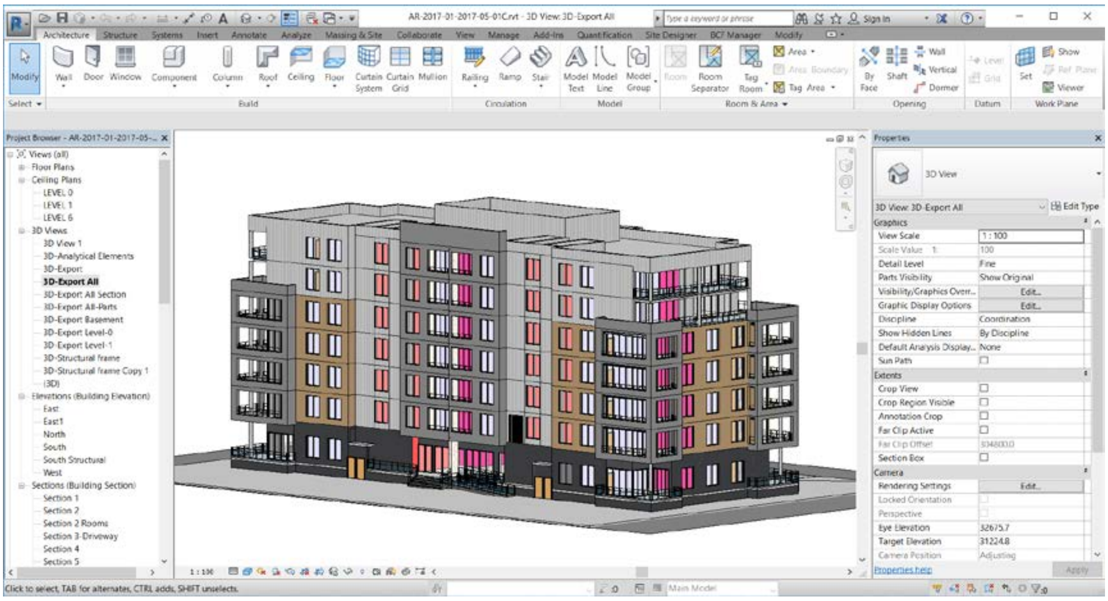
Figure 5: *Proposed workflow*

2.3.1 Building geometry including the layout and configuration of spaces

At the conceptual level, it is not necessary for architects to provide intricate details of a building to the thermal modelling engineers. A building model might comprise only the shell of a building with just walls and floors. Simulations should be carried out to identify any inaccuracies in the model. Engineering judgement can be very useful in this step. If energy consumption of a building significantly deviates from a similar building, there might be disjointed walls/openings/ducts. These should be identified and rectified before moving to the next stage. Internal walls and partitions should be added in the subsequent stage and simulation should be carried out to check for flaws. Figure 6 shows a conceptual model in DesignBuilder and corresponding detailed model in BIM. This clearly demonstrates that a BEM is often an abstract representation of the original BIM.



(a)



(b)

Figure 6: *(a) An example of a simple model without intricate parts in DesignBuilder software and (b) the BIM in Revit*

2.3.2 Building construction including the thermal properties of all elements

In the next step, the BIM should be updated with the thermal properties of all construction elements including walls, floors, roofs, ceilings, windows, doors, and shading devices. This can also be easily updated in the thermal model. Figures 7 and 8 provide examples of information required in this stage in typical thermal modelling software.

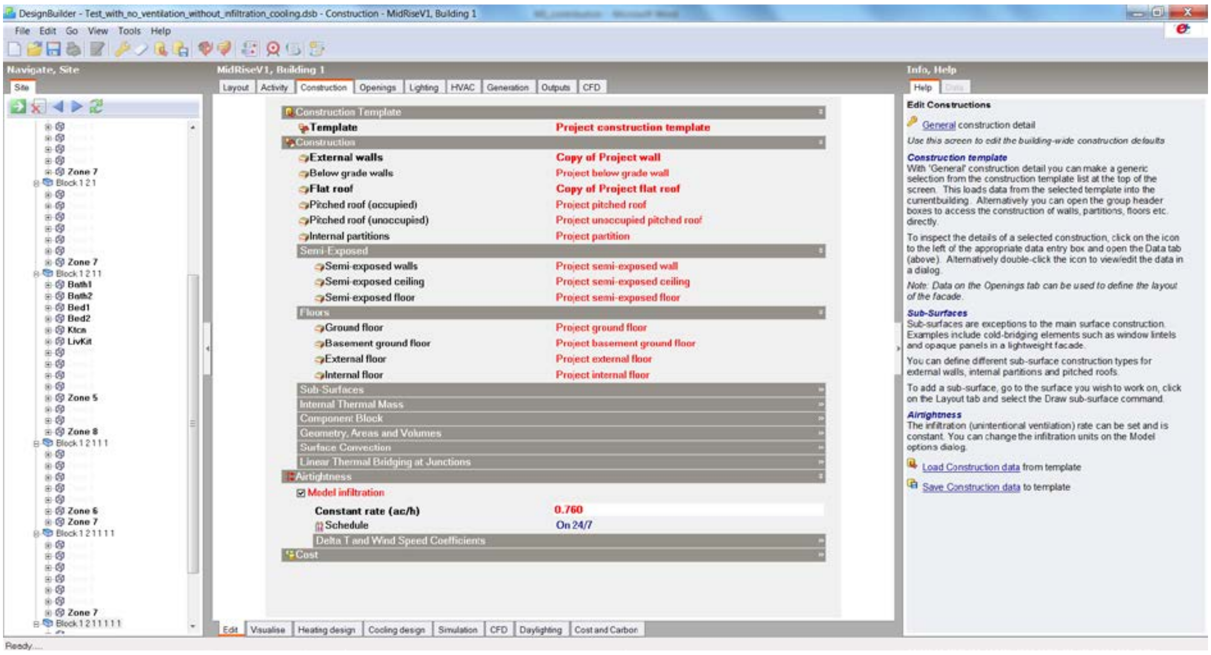


Figure 7: Typical construction information that should be provided for thermal modelling software (DesignBuilder)

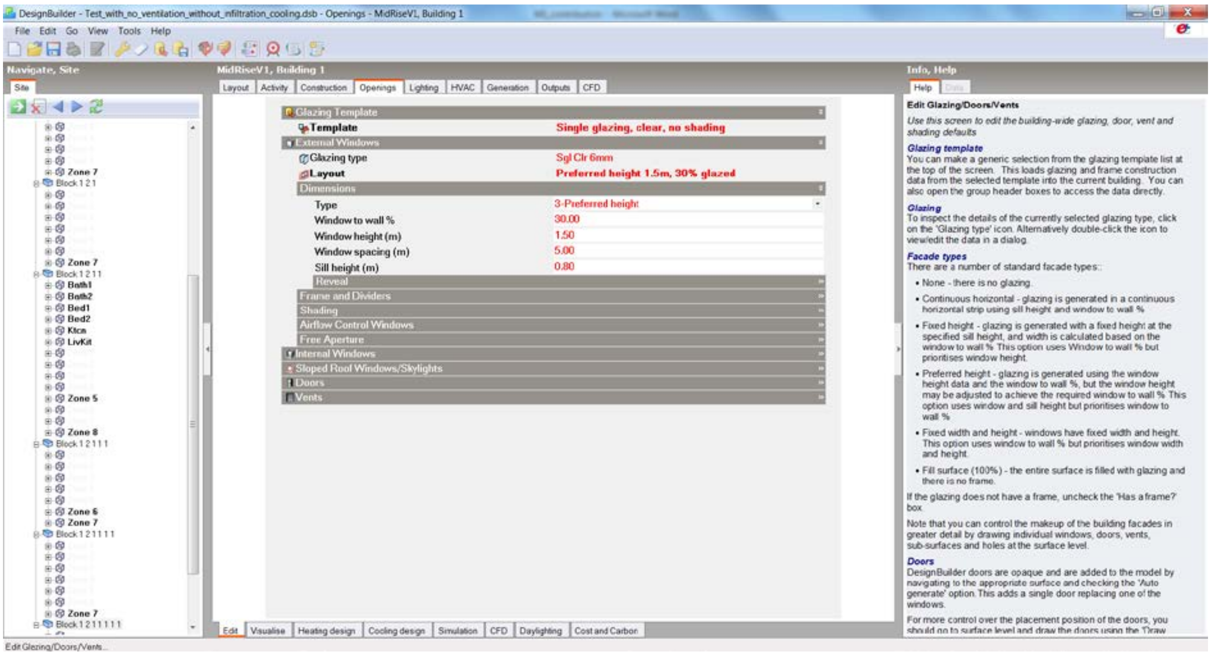


Figure 8: Typical information for openings (window/door/vents) that should be provided for thermal modelling software (DesignBuilder)

2.3.3 Building usage including functional use

Building usage including functional use can be provided after the BIM is updated with the element properties listed in the previous stage. Functional use includes conditioned/unconditioned space, HVAC, lighting and any on site power generation. Figures 9 and 10 provide typical information required in thermal modelling software, appropriate at this stage. Figure 11 illustrates room data available for checking through Solibri Model Checker.

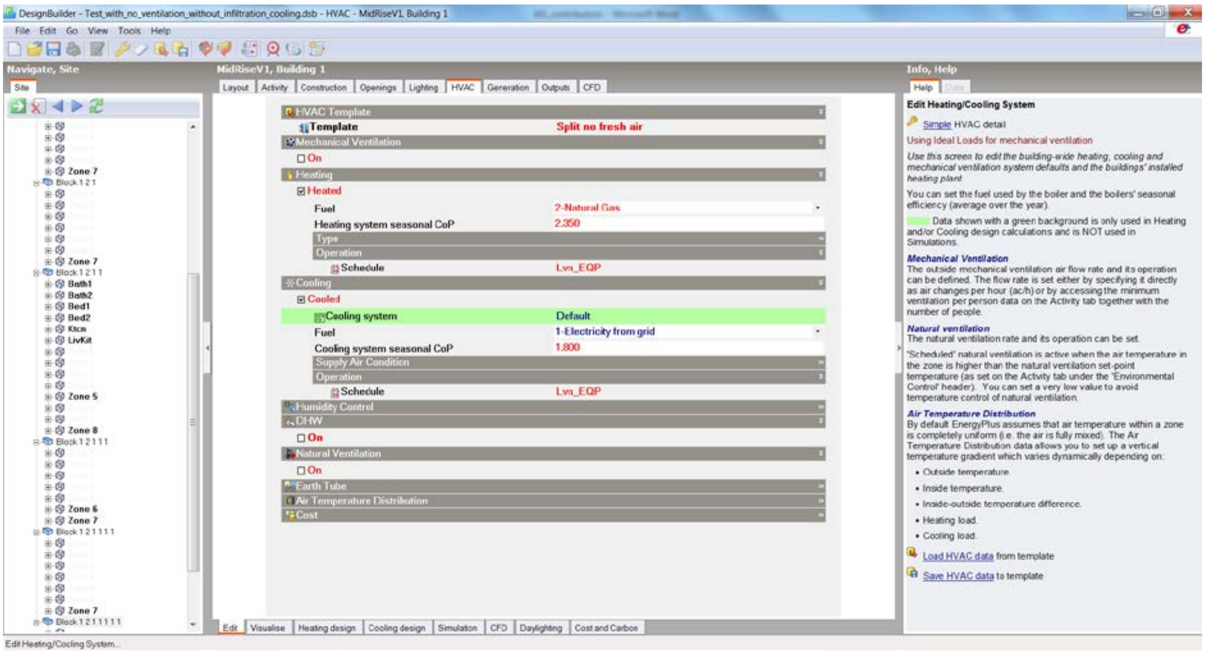


Figure 9: Typical information required for HVAC (DesignBuilder)

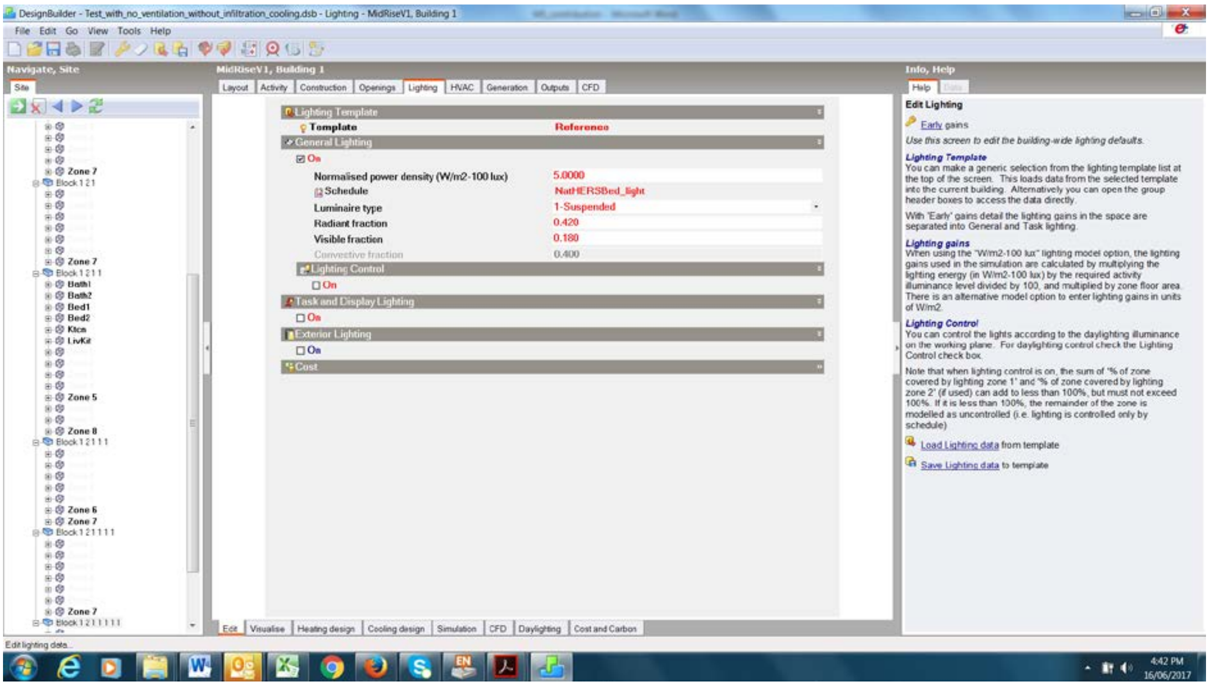


Figure 10: Typical lighting information required (DesignBuilder)

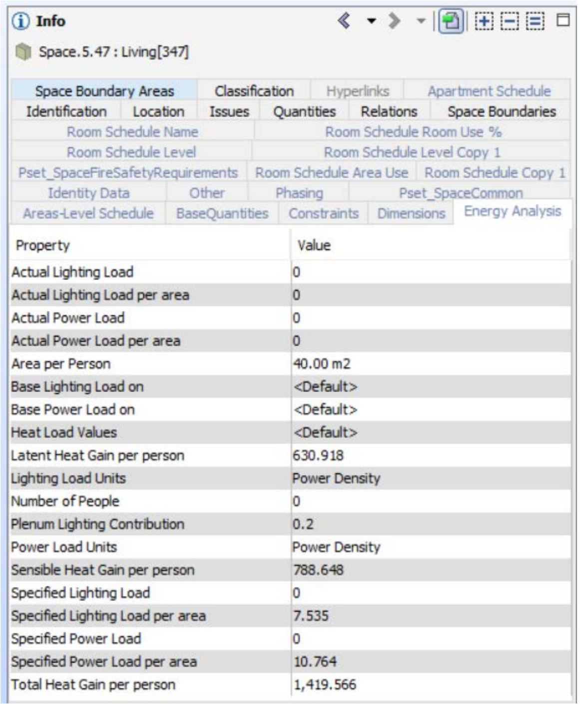


Figure 11: Room data available from models illustrated through Solibri Model Checker

3.0 CONCLUSION

This paper has presented a methodology for iterative, collaborative exchange between the design and energy modelling processes. It is evident that the adoption of both BIM and BEM within the construction industry is growing, and needs to continue to do so in order to meet the increasing imperative for a sustainable built environment. However, the interoperability of BIM and BEM remains problematic. Frameworks for the exchange of data between the two exist, and the IDM addresses the metadata transfer; however, at times practical issues prevail, especially issues of geometric continuity. Geometric model checking is essential, and the use of automated model checking can assure consistency and quality in this process.

In the context of a complex building design, early collaboration is critical to ensure that any modelling discrepancies are dealt with before complexity is added to the models. The reason for this is that when the models reach the more complex stage, it becomes increasingly difficult to detect and resolve any issues in the BEM. Because of the complexity of the BIM, the energy modeller typically resorts to creating a simplified version of the building model for his/her own purposes. Then, the potential for the BEM to inform an iterative design process, optimised for low and no cost energy efficiency solutions, is lost. Whilst it has been anticipated that building simulation software developers will accommodate necessary pre and post-processing within their import and export functions, it would appear from our own research experiences that this is not yet the case with some of the most commonly used BIM and BEM softwares. This paper advocates for the need for further work in the development of the software packages to better support the industry to collaborate from the earliest iteration of a building design. Therefore, this methodology cannot and does not address all of the barriers to an integrated BIM and BEM. However, it provides a framework to help smooth this problematic but important step in the design process for sustainable buildings.

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